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DRIVE LASER TEMPORAL SHAPING TECHNIQUES FOR SHANGHAI SOFT X-RAY FREE ELECTRON LASER*

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Abstract

The design of Shanghai soft X-ray free electron laser (SXFEL) is based on laser driven photocathode, which can provide normalized emittance <2.5 mm·mrad with 500 pC charge. The temporal shape of drive laser has significant influence on the electron beam brightness. This paper presents the transport line of drive laser system and the temporal shaping techniques for SXFEL. This drive laser produces 8 picosecond 266nm ultraviolet pulses with repetition rate 10Hz. A transverse deflecting cavity was used for indirectly characterizing the laser pulse temporal structure. Here we present the drive laser system with its temporal shaping method, and measurement results.

INTRODUCTION

Drive laser is a crucial component for photo injector producing high density, high brightness electron bunches. The pulse parameters of drive laser determine the properties of electron bunches, such as bunch length, bunch charge, the stability of the produced charge, and its synchronization accuracy to the RF of the photo injector, as well as the emittance of the electron bunches [1-3]. Simulation and experiment indicate that flattop pulse can help photoinjector generate uniform temporal and spatial electron distribution with lower transverse emittance [4-6]. Therefore, effective temporal pulse shaping methods are important to photoinjector laser system. The pulse length required for excitation photocathode are around 260nm, 5~10ps with flattop distribution. Several methods have been explored with their pros and cons, such as α-BBO crystal stacking [7-8], double prism or grating pair stretcher [5]. Presently, Simulation also indicates that quasi ellipsoidal laser pulse can help producing electron bunches with minimized emittance [9].

Table 1 shows the laser parameter requirement of Shanghai soft X ray free electron laser (SXFEL). Currently, no commercial laser system can provide all the requirements. Therefore, an integrated laser system based on α-BBO crystal stacking was developed for producing 8ps ultraviolet (UV) pulse. The temporal structure was characterized by cross correlation method with difference frequency generation (DFG) crystal. By illuminating the UV pulse to copper photocathode RF gun, 10 Hz repetition rate ultrashort electron bunch was produced with emittance less than <2.0 mm·mrad with 500 pC charge.

Table 1: Drive Laser System Requirements

Name	Parameters
Wavelength	260 nm~270 nm
Repetition rate	1~10 Hz
Pulse energy on the photocathode	150 µJ
Energy stability in UV	<2.0%rms
Spatial profile	Flat top
Laser spot radius on photocathode	0.5~1.5 mm hard edge radius
Laser spot diameter jitter at photocathode	2% rms radius
Pointing jitter	<2% rms radius
Pulse shape	Flat-top
Pulse duration	Flat-top 10ps edge to edge
Timing stability	< 0.25 ps rms

DRIVER LASER SYSTEM

Figure 1 shows the schematic of driver laser system which consists 4 main stages, 1) Oscillator, 2) Amplifier, 3) Frequency tripled modulator, 4) α-BBO crystal stacking. An oscillator (Vitara-T, Coherent Inc.) pumped by 4.88 W Verdi (Coherent Inc.) deliver 800 nm, 0.7 W pulse (79.33 MHz, horizontal polarization) to Ti:sapphire amplifier (Spitfire Ace PA, Spectrum Physics Inc.). The pre-amplified pulses (8.8 nJ) are firstly stretched to 200 ps using grating pair, then amplified to 5 mJ by regenerative amplifier, and further amplified to 10mJ by single pass amplifier. Finally the amplified pulse are compressed to 1ps (10 mJ) and delivered to third harmonic generation (THG).

The compressed pulses was converted from 800 nm to 400nm by second harmonic generation in a β-BBO crystal (type I, o + o = e, 0.5 mm, θ =29.2°), and subsequently sum-frequency generated in a second β-BBO crystal (type I, 0.5 mm, θ=44.4°). The conversion efficiency from 800 nm to 266 nm was about 2%. As shown in Fig. 1, temporal pulse shaping at 266 nm was conducted by 3 pieces of α-BBO crystals.

The transverse homogenisation shown in Fig. 2 was achieved by selecting the centre part of intensity profile using iris, which was then relay imaging to the photocathode shown in Fig. 1.

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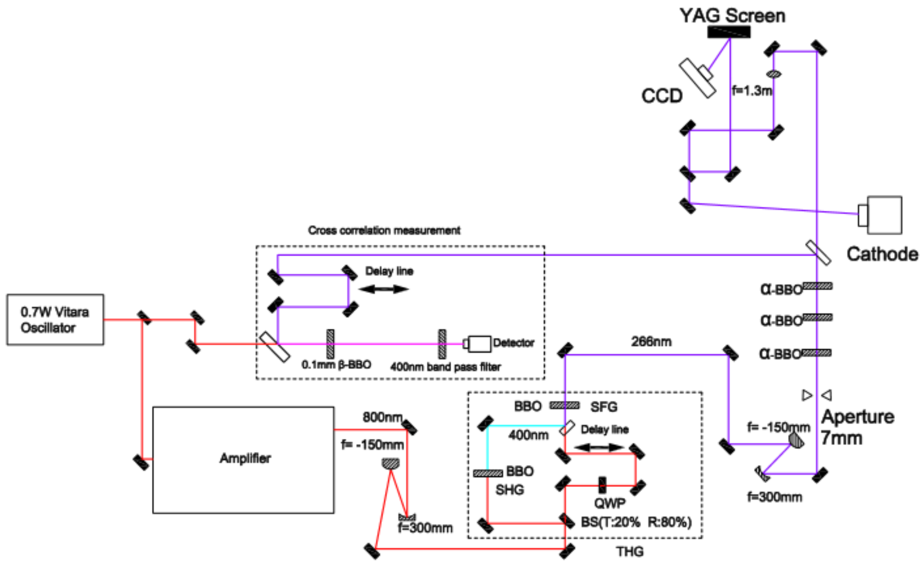

Figure 1: Schematic drawing of SXFEL drive laser system.

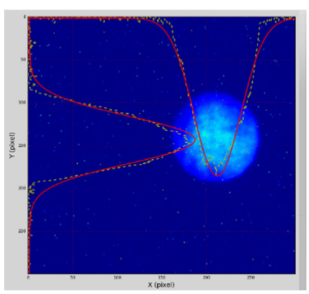

Figure 2: Transverse intensity distribution captured on virtual cathode.

UV PULSE SHAPING WITH BIREFRINGENT CRYSTALS

A brief description of the UV pulse shaping method is presented here. More detailed description can be found in references [7]. α-BBO crystals are anisotropic materials that have different indices of refraction for s, p polarization. Ordinary (o) beam has a polarization perpendicular to the optical axis of crystal, while extraordinary (e) beam has a polarization parallel to the optical axis. For α-BBO crystals, the Sellmeier equations for $n_e(\lambda)$ and $n_o(\lambda)$ are expressed in Eq. (1) and (2) [7-8].

$$n_o(\lambda) = \sqrt{2.7471 + \frac{0.01878}{\lambda^2 - 0.01822} - 0.01354\lambda^2} \quad (1)$$

$$n_e(\lambda) = \sqrt{2.3174 + \frac{0.01224}{\lambda^2 - 0.01667} - 0.01516\lambda^2} \quad (2)$$

Where λ is the wavelength in μm, $n_e(\lambda)$ and $n_o(\lambda)$ are the index of refraction of the o beam and e beam.

The temporal separation (Δt) between o beam and e beam when they propagate through the BBO birefringence crystal is given by Eq. (3).

$$\Delta t = L * GVM \quad (3)$$

Where L is the thickness of crystal, Group velocity mismatch ($GVM = (n_e(\lambda) - n_o(\lambda))/c$), c is the speed of light.

Figure 3 shows 3 α-BBO crystals were used for producing 8 ps flat-top 120 μJ UV pulse. The input Gaussian pulse is linearly horizontal polarized while the optical axis of the first BBO crystal with thickness L_1=4.3306 mm is oriented at 45° relative to the horizontal direction. For α-BBO, e beam (parallel to the optical axis of crystal) will move ahead of o beam (perpendicular to the optical axis of crystal) by an amount of Δt_1=4 ps.

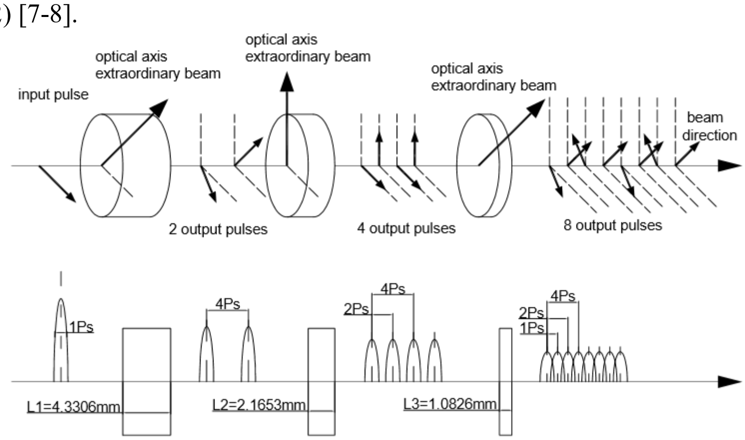

Figure 3: Schematic diagram showing 3 birefringent crystals used to produce 8ps temporal flattop pulse.

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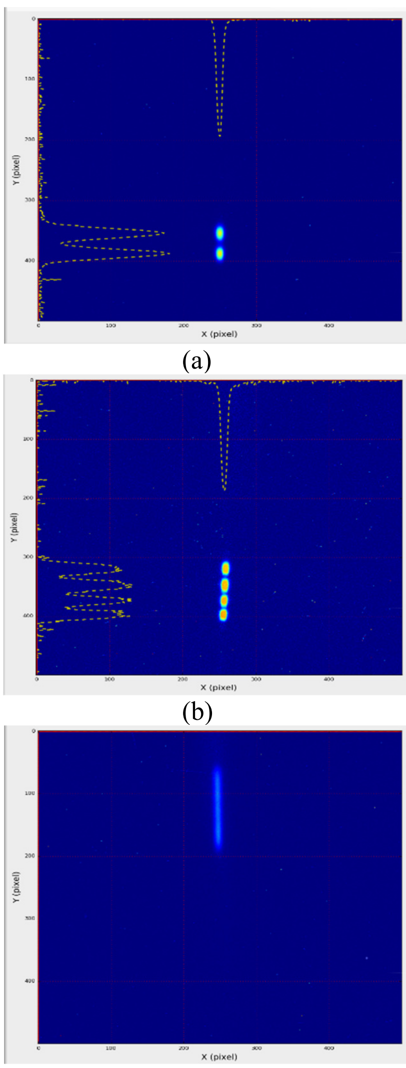
According to Eq. (1) and (2), for λ =266 nm n_e=1.594, n_o=1.761, the *e* beam is the fast axis. The 45° orientation creates equal intensity for *o* beam and *e* beam. The relative intensity between the two beams can be controlled by a rotation of crystal axis. The two pulses emerging from the first crystal oriented at 45° to the vertical. The optical axis of second BBO crystal oriented in vertical direction. When the two intermediate pulses pass through the second crystal with thickness L_2=2.1653 mm, each pulse is divided into 2 more pulses separated by Δt_2, thus producing 4 pulses. Finally, the four pulses pass through the third crystal with thickness L_3=1.0826 mm, the optical axis of third crystal oriented at 45° relative to vertical direction. When the four pulses pass through it, 8 pulses with separation by Δt_3 are produced. The temporal structure of the UV pulse was indirectly characterized by a transverse deflecting cavity. The measured electron beam temporal structure, as shown in Fig. 4, indicated the stacking procedures and the UV pulse has a good temporal distribution.



(a)

(b)

(c)

Figure 4: Electron bunch length measurement result from transverse deflecting cavity.

CONCLUSION

We present the design of drive laser system for SXFEL and investigate UV pulse temporal shaping technique based on BBO stacking method. Transverse deflecting cavity measurement results show stacking procedure for producing one 8ps length bunch. Further investigation will attempt to characterize the relationship between the UV pulse temporal structure and corresponding electron beam emittance.

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